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LECTURE NOTE

SPATIAL AND TEMPORAL ESTIMATION OF SOIL EROSION USING REMOTE SENSING AND GIS

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INTRODUCTION

Land degradation from water-induced soil erosion is a serious global problem, which is not only eroding the top fertile soil but is also responsible for swelling of river beds and reservoirs thereby causing floods and reduction in the life span of costly reservoirs and dams. Though it is difficult to assess reliably and accurately the rate and magnitude of runoff and associated soil loss, the information available in literature, which is often based on reconnaissance surveys and extrapolations, provides an idea of the severity of this problem. Judson (1981) estimated that river-born sediments carried into the oceans increased from 10 billion tones per year before the introduction of intensive agriculture, grazing, and other activities to 25-50 billion tones per year thereafter. Dudal (1981) reported that the current rate of agricultural land degradation worldwide by soil erosion along with other factors led to an irreversible loss in annual productivity of about six million ha of fertile land. Narayana and Babu (1983) estimated that about 5334 million tones of soil is being eroded annually in India, due to which 8.4 million tones of nutrients are lost. Another estimate reveals that the average soil loss in India is about 16.3 tones per ha per year against the permissible range of 5-12.5 tones per ha per year for various regions (Narayana, 1993).

Reliable estimates of soil erosion and sediment yield are, therefore, required for design of efficient erosion control measures, reservoir sedimentation assessment, water quality management, and evaluation of watershed management strategies. The detachment and displacement of soil particles over short distances, referred to as erosion, do not wholly represent the sediment delivered at the watershed outlet known as sediment yield. Much deposition and reduction in sediment load occurs between the sediment sources and the outlet (Narayana and Babu, 1983). Sediment yield is limited by the transport capacity of runoff (Beasley et al., 1980; Morgan, 1995). Measurement of sediment yield on a number of watersheds is operationally difficult, expensive, time consuming, and tedious, and therefore modelling is carried out for simulating, generating or augmenting the sediment yield data base.

The rain falling on a watershed undergoes a number of transformations and abstractions through various component processes of hydrologic cycle, viz., interception, detention, evaporation and evapotranspiration, overland flow, infiltration, interflow, percolation, base flow etc., and finally emerges as runoff at the watershed outlet. These component processes are functions of various climatic and watershed characteristics, such as rainfall intensity and duration, topography, land use and vegetation cover, drainage pattern, drainage density, geology etc., which are not uniform in time and space. Soil erosion by water that refers to the removal of soil particles from the land surface due to erosive action of water involves detachment of soil particles by raindrop impact and shear stress of overland flow, transport of detached particles by overland flow, and deposition of soil particles (Meyer and Wischmeier, 1969).

MECHENICS OF SOIL EROSION BY WATER

When raindrops fall on the ground, soil particles are detached and splashed upward due to the kinetic energy of drops. The higher the rainfall intensity, the greater will be the splash and amount of soil detached. Upon returning to the soil, splashed particles disperse and clog soil pores, causing surface crusting and a reduction in the soil's infiltration rate. The pounding action of rain may also compact the soil, further decreasing infiltration. When water is applied in excess of the soil's infiltration rate, water will puddle and the runoff leads to additional detachment of soil particles due to shear stress of flow, and transport of these particles by the flowing water. Particle transport by water requires a critical speed to effectively carry sediment; when water velocity slows below this speed, deposition occurs. Because coarse particles fall out of suspension sooner than fine particles as runoff velocity slows down, they are more apt to remain on the field while fine particles are moved farther downstream. Thus, the soil loss is greatly influenced by the intensity of rainfall, rate of overland flow, vegetation cover, and soil texture.

Main Forms of Soil Erosion

Three main forms of water erosion are sheet, rill and gully erosion.

Sheet erosion

Soil erosion resulting from raindrop splash and surface runoff is often called as sheet erosion. This is the uniform removal of soil in thin layers from slopping surfaces of soil between rills. Although important, sheet erosion is often unnoticed, because it occurs gradually. The raindrops cause the soil particles to be detached and the following sedimentation reduces infiltration rate by sealing the soil pores

Rill erosion

When water takes the path of least resistance to flow over the soil surface, it forms minute channels or rills, and rill erosion occurs. Rill erosion is the removal of soil by water from small but well advanced channels in which the overland flow concentrates. Detachability and transportability of soil particles are both greater during rill erosion than during sheet erosion, because of higher velocities. Rill erosion is most serious in regions where the storms are of high intensity and the top soils are loose and shallow.

Gully erosion

Gully erosion occurs when large quantities of runoff concentrate and create large channels in the landscape. Gullies are relatively permanent features that cannot be removed by tillage. These channels carry water during and immediately after rains. Gullies are usually formed by (i) water fall erosion at the gully head, (ii) channel erosion caused by water flowing through the gully, (iii) alternate freezing and thawing of the exposed soil banks, and (iv) slides and mass movements of soil in the gully

Factors Affecting Erosion and Sediment Yield

The four principal factors that affect soil erosion and the quantity of sediment that may reach the outlet of a watershed are climate, soil properties, watershed characteristics and land cover characteristics. The effects of these factors on erosion and sediment yield are briefly described below.

Climate

Intensity, duration and frequency of rain events all appear to play a role in the amount of soil that erodes. In general, the most severe erosion occurs when rains are of relatively short duration, but high intensity. Heavy raindrop action coupled with higher rain intensity than the soil infiltration capacity can lead to high surface runoff and large soil loss. Long, low intensity storms can also be highly erosive due to saturated soil conditions causing increased runoff (Morgan, 1995). Soil detachment by wind driven rain is different from that by rain falling under calm air (Lal, 1976). The wind action on rain drops may add to their erosive energy and also may increase the velocity of flow and thereby its transport capacity. The temperature plays an important role in the process of weathering which leads to disintegration of rocks. Temperature also affects runoff and hence the sediment yield.

Soil Properties

Soil properties affecting water erosion and sediment yield include those that influence infiltration and soil stability, such as texture, organic matter, aggregation, soil structure and tilth. Soil erodibility or the vulnerability of soil to erosion refers to the resistance of soil to both detachment and transportation (Wischmeier and Smith, 1978). Key factors that affect erodibility are soil texture, soil permeability, soil structure, and amount of organic matter. Because water readily infiltrates into sandy soils, the runoff, and consequently the erosion potential, is relatively low. Clay, because of its stickiness, binds soil particles together and makes it resistant to erosion. However, once heavy rain or fast flowing water erodes the fine particles, they will travel great distances before settling.

Catchment Characteristics

Catchment area, slope, and drainage density are some of the catchment characteristics that influence the runoff production and thus the sediment yield (Jansen and Painter, 1974). Because fast moving water can carry more sediment than slow moving water, there is a greater potential to lose a larger amount of material on steep slopes than gradual slopes (Morgan, 1979). Many researchers have investigated the effect of slope steepness on the erosion and found a relationship of the form of ($y = ax^b$); where y is the erosion, x is the slope steepness, a and b are the constant and exponent (Zingg, 1940). Schumm (1954) demonstrated the variation of sediment delivery ratio with catchment area and derived an inverse correlation between sediment yield per unit area and the area.

Land Cover

Vegetative cover reduces detachment of soil particles by intercepting raindrops and dissipating their energy. Type of land use and vegetative cover also influence the overland flow in terms of the roughness (Chow, 1959). Surface vegetation and residue act as dams that slow down flow velocity and promote deposition. Roots of vegetation play significant role in reducing the soil erosion by binding the soil mass to increase its resistance to flow.

MODELLING SOIL EROSION AND SEDIMENT YIELD

Models available in the literature for estimation of soil erosion and sediment yield can be grouped as (a) empirical and (b) Physically-based. Empirical models, which mainly include the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) and its extensions viz., Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) and the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1991), combine the soil erosion from all processes in the catchment into one equation which make use of empirical coefficients to represent the rainfall characteristics, soil properties, ground surface conditions, etc. These methods are simple in application and hence frequently used in different parts of the world (Julien & Tanago, 1991).

The physically-based models attempt to solve the fundamental equations for transport of water and sediment. In reality, the physically-based models still rely on empirical equations to describe erosion process and, therefore, they are termed as process-based models. Process-based models are generally spatially-distributed models that are capable of taking into account the spatial heterogeneity prevalent in catchment area by subdividing it into smaller homogeneous areas. These models are, therefore, expected to simulate the process of rainfall-runoff and soil erosion more realistically and provide reliable results. Some of the process-based models for soil erosion include ANSWERS (Beasley *et al.*, 1980), WEPP (Nearing *et al.*, 1989), AGNPS (Young *et al.*, 1987), SHESED (Wicks & Bathurst, 1996), and SWAT (Arnold et al., 1993), among others.

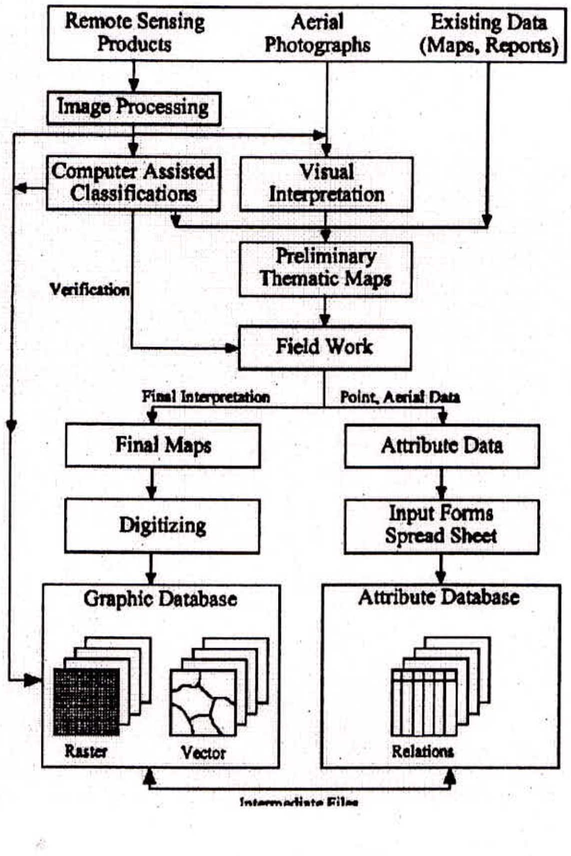
REMOTE SENSING & GIS FOR DISTRIBUTED MODELING

The distributed rainfall-runoff-sediment yield models have the capability to account for the spatial variability of watershed characteristics and predict the spatial distribution of runoff and sediment over the land surface in addition to total runoff and soil loss. But, the major constraint in applying these models is their large and space-time variable input data requirement, which are scanty in the country (Sarangi et al., 1999). The Remote Sensing (RS) and Geographic Information System (GIS) capabilities these days, however, provide easy solution to this problem. While satellite remote sensing technique makes it possible to measure hydrologic parameters on temporal and spatial scales, the GIS integrates the spatial analytical functionality for providing spatially distributed data.

Remote sensing and its associated image processing technology provide access to spatial and temporal information on watershed, regional, continental and global scale. Measurements may be carried out from ground (field measurements) but the advantage of remote sensing applications in hydrology, as a source of spatial information (in opposition to point measurements) becomes more obvious if sensors on air or space borne plate forms are used. The sensors measure the spectral characteristics of interest and their variation with time over large areas, providing data input into various hydrological models. Additionally, remote-sensing data represents an important input into algorithms, which allow the derivation of hydrological parameters.

Effective utilisation of this large spatial data volume is dependent on the existence of an efficient, geographic handling and processing system that will transform this data into usable information. A major tool for handling spatial data is Geographic Information System (GIS). GIS provides appropriate methods for efficient storage, retrieval, manipulation, analysis and display of large volumes of spatially referenced data. In a GIS, data are organised into a series of spatially geo-registered layers, with each layer relating to a particular theme (e.g. vegetation, soils, geology, topography etc) or a set of layers relating to temporal variation of a particular theme (e.g. change in landuse or vegetation or variation of soil moisture etc.). Output from a GIS includes maps, graphs, tabular statistics, and reports, which may be end products or may be employed as input to further analysis.

Remotely sensed data can be best utilised if they are incorporated in a GIS that is



designed to accept large volumes of spatial data. Fig. 1 shows a procedure of deriving both spatial and non-spatial data from remotely sensed data for input into a GIS. Further, successful applications of remote sensing in hydrology have influenced hydrologists to modify existing hydrological models or develop new models to incorporate available spatial data. In many cases, remotely sensed data alone are not sufficient for hydrological purposes and such data have to be merged with ancillary information such as soils, geology and elevation etc. GIS offers an appropriate technology for merging various spatial data layers.

Several studies have been carried out wherein a GIS was used for the determination of the potential soil erosion in different plot size areas (Bocco & Valenzuela, 1988; Omakupt, 1989; Jurgens & Fander, 1993; Jain & Saraf, 1995; Dutta *et al.*, 1995). In the last decade, GIS techniques have been widely used by researchers in watershed modeling to capture the spatial variation in computed quantities. Needham and Vieux (1989) examined the application of ARC/INFO GIS to generate spatial input data for the Agricultural Non-Point Source Pollution (AGNPS) model. Using a GIS, Van Blargan *et al.* (1990) generated data for a hydrologic model. Moore *et al.* (1988) utilized ARC/INFO to provide topographic attributes for modeling hydrology and water quality in a watershed. Olivieri *et al.* (1991) developed a method for automated generation of input data for the AGNPS model by using the ERDAS GIS software.

GIS techniques have also been interfaced with some hydrological models of both distributed and empirical nature. The AGNPS model for computation of soil erosion rates is interfaced with the GRASS GIS system (Srinivasan and Engel, 1994). Rewarts and Engel (1991) interfaced ANSWERS model and GRASS system. Mashriqui and Cruise (1997) interfaced a GIS with the SLURP model for sediment yield modeling based upon homogeneous hydrological and sediment response units. Kothyari and Jain (1997) have used a GIS for estimation of sediment yield resulting from isolated storm events. SWAT model is interfaced with Arc GIS to account for the spatial variability in the catchment characteristics.

ESTIMATION OF SPATIAL SOIL EROSION USING GIS – A USLE APPROACH

Simple methods such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) are quite frequently used for estimation of soil erosion in catchment areas (Ferro and Minacapilli 1995; Ferro 1997; Kothyari and Jain, 1997; Ferro *et al.*, 1998; Jain and Kothyari, 2000; Kothyari *et. al.*, 2002). The USLE was developed to estimate the long term average soil loss from sheet and rill erosion on a specified land in a specified cropping and management system. The limitation of this model is that it does not estimate deposition, sediment yield, channel or gully erosion. The essence of USLE is to isolate each variable responsible for erosion and reduce its effect to a number so that when the number of different variables are multiplied together, the answer is the soil loss. The USLE is represented as:

$$A = R*K*L*S*C*P$$

Where,

A is the computed soil loss in tones/ha/year.

R is the rainfall erosivity factor, which is the number of rainfall erosion index units for a particular location. It is taken as the long term average of the summation of the product of total rainfall energy (E) and maximum 30 minute rainfall intensity (I_{30}), i.e. EI_{30}.

K, the soil erodibility factor, is the soil loss per erosion index unit for a specified soil as measured on a unit plot which is defined as 22.13 m long of uniform 9% slope and tilled continuously fallow. K factor is a function of the percentage of silt and coarse sand, soil structure, permeability of soil and the percentage of organic matter.

L, the slope length factor, is the ratio of soil loss from the field slope length to that from a 22.13 m length under identical conditions.

S, the slope steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P, the supporting practice factor, is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight row farming up and down the slope.

The equation groups the numerous interrelated physical and management parameters that influence the erosion rate under six major factors, of which site specific values can be expressed numerically (Singh et al., 1981).

Application of USLE

Study Area

The study area selected for soil erosion modeling is Sitlarao sub-watershed which is located in the western part of the Doon valley, Dehradun district, Uttarakhand. This sub-watershed belongs to the Asan river system, which is a tributary of Yamuna river. The area lies between 77° 45′ and 77° 57′ E longitude and 30° 24′ and 30° 29′ N latitude covering approximately 52 km^2. The altitude varies from 440 to 2300 m above msl. The soil types found in the study area are Loam, Gravely Loam, sandy Loam, Loamy Sand etc. Depending on the elevation, rainfall varies from 1600 to 2200 mm most of which fall during monsoon months. The major land use in the study area is forest, agriculture and waste land.

Data Used

(i) Remote Sensing data: IRS-1C-LISS III.

(ii) Ancillary data: Survey of India toposheet, physiographic soil map of Doon valley, and attribute data of ‘K’, ‘C’ and ‘P’ factors pertaining to the soil units and land use classes existing in the study area.

Generation of Maps

In the present study, ILWIS (ITC, 1992) was used for preparation of maps and analysis of data. ILWIS is a GIS package that integrates image processing and spatial analysis capabilities, tabular database and conventional GIS characteristics. The base map of the study area was prepared from the SOI toposheet at a scale of 1:50,000. Drainage network, roads and important point locations like villages, temples etc. were digitized as segment map and point map respectively. For creation of Digital Elevation model (DEM), the contours were digitized from the toposheet.

A contour interpolation algorithm in ILWIS was used to create DEM from the contour map. Slope map was calculated from DEM using the *dfdx* and *dfdy* filters and the appropriate slope calculation formulae. The slope was calculated in percentage as it is required in USLE.

The rainfall distribution map was prepared using the relationship between elevation and rainfall (Shreshta, 1997) as,

$$\text{Rain} = 1384.2 + 0.339 * \text{elevation}$$

The resulting rainfall map showed different values of rainfall for each pixel. Using a suitable domain, a classified rainfall map was therefore prepared.

The soil map was digitized from the physiographic soil map of the area. It consisted of 14 soil units named as H11, H12, H13, H21 (soils of residual hills), M1, M2, M3 (soils of mountainous areas), P11, P12, P21, P22 (soils of piedmont areas), V1, V2, and V3 (soils of river terrace).

The land use map was prepared by digital image processing of IRS-1C, LISS III data of Feb. 1998. The different land use classes were identified as dense forest, degraded forest, cultivation, mixed forest, fallow land, open scrub, and river.

Estimation of USLE Parameters

Rainfall energy factor (R): In India, research has shown that R factor can be calculated using the following relation (Singh et al., 1981).

$$R = 79 + 0.363*X$$

where X is the average annual rainfall in mm. Using the above relation and the rainfall map generated from the DEM, the R factor map was computed as shown in Fig. 2.

K factor: The spatial distribution of K values in the study watershed was produced in the form of a K factor map (Fig. 3). For this purpose, K values were taken from the attribute data pertaining to the soil units of the area.

L factor: As L is the ratio of field soil loss to the corresponding soil loss from 22.13 m slope length, its value may be expressed as,

$$L = (\lambda/22.13)^m$$

Where λ is the field slope length (m) and m assumes the value of 0.2 to 0.5. Wischmeier and Smith (1978) have come out with varying values of 'm' for different slopes as given below.

Slope gradient	Value of m
1%	0.2
1-3%	0.3
3-4.5%	0.4
above 4.5%	0.5

A map showing the distribution of m values was created using the slope map as input. The L factor map was then computed by taking the field slope length as grid size (25 m) as follows.

$$L = (25/22.13)^m$$

S factor: For creating the S factor map, the following relation given by Wischmeier and Smith (1978) was used.

$$S = (0.43 + 0.30\,s + 0.043\,s^2) / 6.613$$

where s is the slope in percentage. The combined *LS* factor map (Fig. 4) was calculated by multiplying the L and S factor maps.

C and P factors: The values of C and P factors for different land uses were taken from the land use attribute data, and the attribute maps showing the spatial distribution of C and P factors were generated (Fig. 5 & 6).

Fig. 1: Spatial and non-spatial data generation through remote sensing and GIS

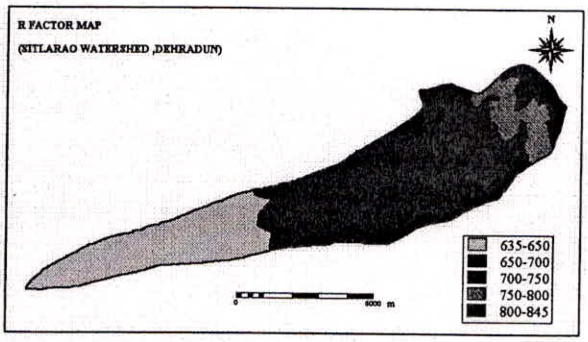


Fig. 1

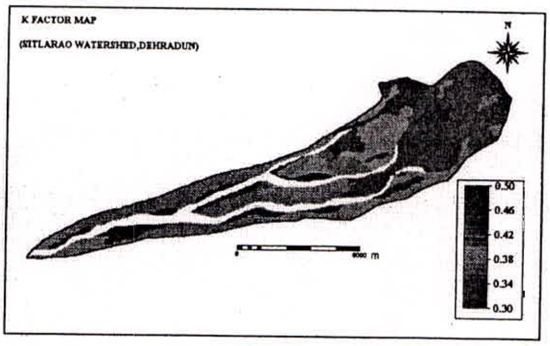


Fig. 2

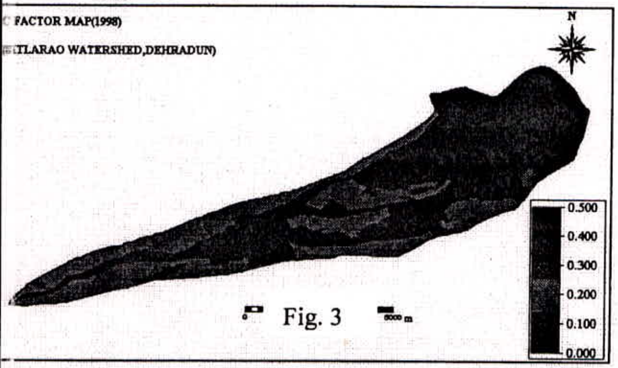


Fig. 3

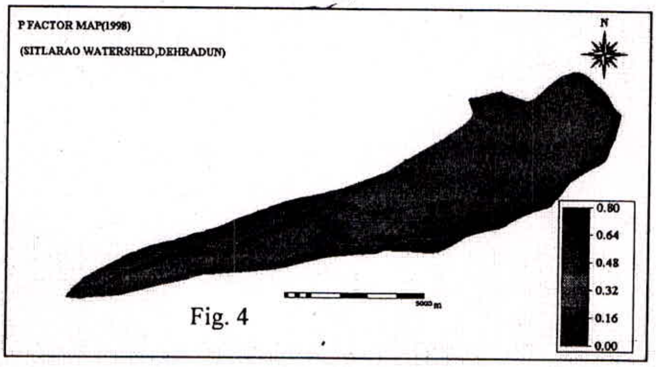
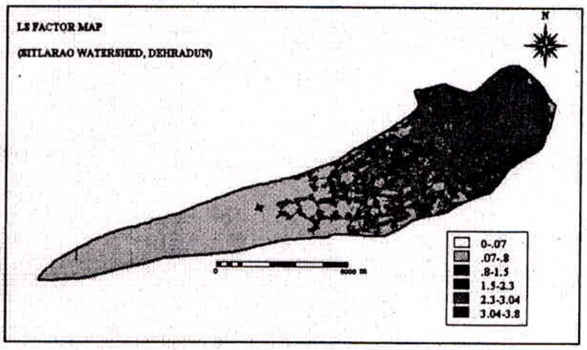


Fig. 4



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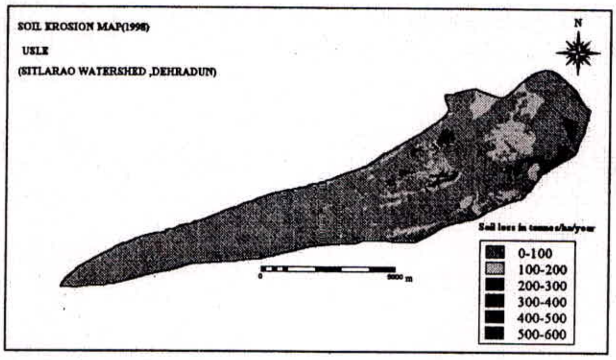


Fig. 6

Estimation of Soil Loss

All the factors mentioned above, generated in the form of maps, were integrated in GIS to produce the final soil loss map using USLE.

Estimation of Soil Loss per Land Use Type

The soil loss map was crossed with the land use map and aggregated to calculate the average annual soil loss from different land uses (Table 1). As can be seen from Table 1, the forested areas show lowest soil loss. Mixed forest areas show moderate soil loss owing to steep topography at higher reaches. In the cultivated areas, the range of soil loss is high.

Fallow lands and open scrub areas show very high soil loss owing to the poor vegetative cover and shallow roots.

Table 1: Estimation of soil loss per land use type.

Landuse	**Area (sq.kms)**	**Average annual soil loss in tonnes/ha/year**
Cultivation	17.93	53.92
Dense forest	10.02	1.98
Degraded forest	0.66	8.95
Mixed forest	5.02	65.17
Open scrub	5.46	129.86
Fallow	4.93	198.66
Snow	1.51	0
River	6.28	0

Estimation of Soil Loss per Physiographic Soil Units

To estimate the average soil loss from different physiographic soil units, the soil map was superimposed with the soil loss map and aggregated. Average annual soil loss from different soil units is presented in Table 2. It is clear from the table that the soil units in the mountainous region are more prone to erosion as the range of soil loss for these units (M1, M2 and M3) is clearly more than that for the other soil units. The soil units of the lower areas such as H11, H21, P11, P21, P22, V1 and V2 show low soil loss. This is attributed to the lower elevation, gentle slope, and good vegetative and forest cover.

Soil units	**Area (sq.kms)**	**Average annual soil loss in tonnes/ha/year**
H11	2.34	62.26
H12	2.61	95.11
H13	0.24	52.99
H21	3.12	43.03
M1	1.01	67.88
M2	5.79	162.01
M3	0.59	102.11
P11	2.24	49.1
P12	6.66	87.53
P21	4.97	30.31
P22	4.34	43.8
VI	6.6	31.42
V2	4.18	22.67
V3	0.72	70.47

From the above table the average value of soil loss for mountain comes out to be 110.66, for residual hills 63.34, for peidmonts 41.52 and for valley it comes out to be 41.52 t/ha/year. It means that the erosion increases from valley to peidmonts to Residual hills to mountain.

ESTIMATION OF TEMPORAL VARIATION OF RUNOFF AND SEDIMENT YIELD USING GIS INPUT WITH ANSWERS MODEL

ANSWERS, developed by Beasley et al. (1980) is a distributed parameter, event based model used to simulate surface runoff and erosion response of agricultural watersheds. The model divides the entire watershed into uniform grid of square cells within which all input variables (surface and subsurface soil properties, vegetation, surface condition, crop management and weather) are assumed homogeneous. Connectivity of cells and continuity equations are used to route sediment transport and flow. The model can be divided into two parts, (1) hydrologic sub-model and (2) sediment sub-model. The hydrologic sub-model simulates interception, surface retention/detention, infiltration and overland flow. The sediment sub-model considers three erosion processes: detachment of soil particles by impact of raindrops, detachment of soil particles by overland flow and transport of soil particles by overland flow. The quantity of erosion or deposition occurring within each cell is estimated based on the erodibility of the soil and land cover type of the cell, the rate of flow passing through the cell, and the quantity of sediment in the flow passing through the cell. Every element or cell acts as an overland flow plane with a user-specified slope and slope direction. Channel elements collect flow from overland flow elements and route runoff to the watershed outlet. Soil detached from rainfall or runoff is also available for transport by overland flow.

The input data required for each element include (i) topographic data (elevation, slope, and aspect), (ii) soil data (porosity, antecedent moisture content, field capacity, infiltration capacity, and Universal Soil Loss Equation (USLE) 'K' factor), (iii) land cover data (percent cover, interception, USLE 'C' & 'P' factors, surface roughness, and surface retention), (iv) channel data (width, and roughness), and (v) rainfall (break even data). ANSWERS outputs an event hydrograph, an event sediment graph, and the erosion and deposition rates for individual grid cell. In the present study, the RS and GIS techniques were fully employed in applying ANSWERS model to Mansara watershed for simulating runoff and sediment yield from rainfall events (Tyagi and Aggrawal, 2004).

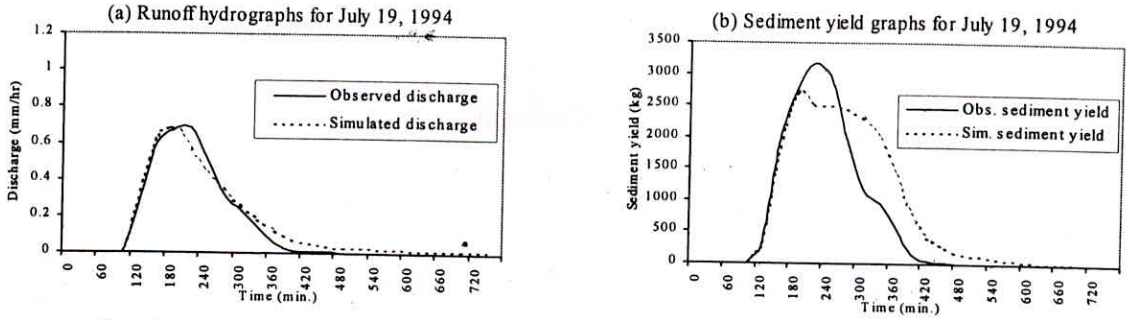
Application of ANSWERS Model

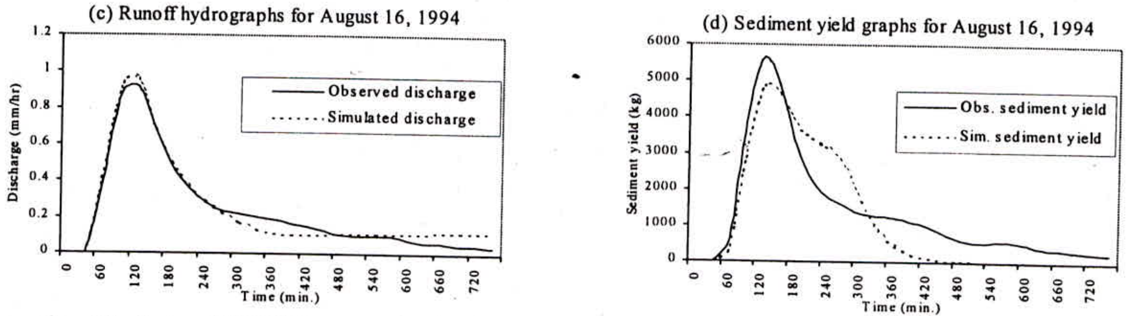
Study Area

Mansara watershed, 870 ha in size, is a part of Gomti river basin and lies in Barabanki district, Uttar Pradesh, between Longitudes 81^0 23′ 42″ to 81^0 26′ 15″ E and Latitudes 26^0 41′ 04″ to 26^0 43′ 15″ N. The slope of the watershed though varies from flat to about 12%, the major area (93%) falls under a slope range of up to 1%. The watershed has one stream that receives the runoff from the overland flow. The watershed has a maximum relief of 7 m. The upper portion of the watershed is subjected to sheet erosion while rills are witnessed in the lower portion. The soils in the watershed are deep alluvial, grouped into three textural classes viz., loam, sandy loam and sandy soils. The watershed is predominantly comprised of agriculturally cropped lands.

Methodology

The ANSWERS model used in the study is a PC-DOS version and requires spatial data input in a text file called 'Elemental Data File'. The data file was generated from GIS layers, which included land use/cover, soil texture, slope, aspect and drainage. The slope and aspect maps were derived from the DEM which was interpolated from the contour map of the watershed. The soil texture map was prepared using the available information on the soils of the watershed. The drainage network was digitized from the watershed map. Land use/land cover map was prepared from IRS-1C, LISS-III and PAN data of Oct.13, 2000. The remote sensing and GIS analysis for the study was carried using the ILWIS software.





Land use map, soil texture map, slope map, aspect map & drainage map reclassified to 100X100 m pixel size, were integrated in GIS environment to obtain integrated properties for each cell. The integrated layer was converted to a text file to describe the cells (pixels) row and column number, slope steepness, direction of slope (aspect), soil type number, land use type number, channel type number (if present in the cell), raingauge designator etc. as per the 'Elemental Input Data File' format. The model was calibrated and validated for the observed response of the watershed. The spatial rates of erosion and deposition across the watershed as predicted by the model were transformed to maps using GIS capabilities.

Model Calibration

Fig. 8: Runoff hydrographs and sediment yield graphs for calibration events

Model parameters for each type of soils, land use and surface characteristics, and channels in the watershed were estimated based on the available data and the literature. The estimated parameter values were fine-tuned during calibration process. Model calibration was carried out on individual storm events of July 19, 1994 and August 16, 1994 with respect to their observed values of surface runoff, peak runoff and sediment yield, and an average set of parameter values was obtained to simulate both the events with a reasonable accuracy. The simulated and observed hydrographs and sediment yield graphs for two calibration events are presented in Fig. 8. The simulated graphs of runoff and sediment yield for both the events show a reasonable match with the observed graphs.

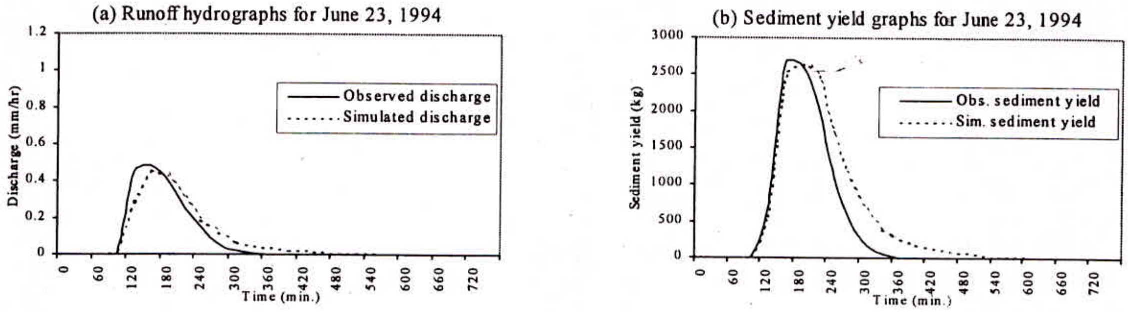
Model Validation

Model validation was carried out on two storm events of June 23rd and July 25th, 1994. Except for time variant parameters, the calibrated values of all other parameters were kept unchanged in the validation process. The values of time variant parameters were estimated and used in the validation. The computed and observed runoff hydrographs and sediment yield graphs for the validation events (Fig. 9) show a reasonably good match.

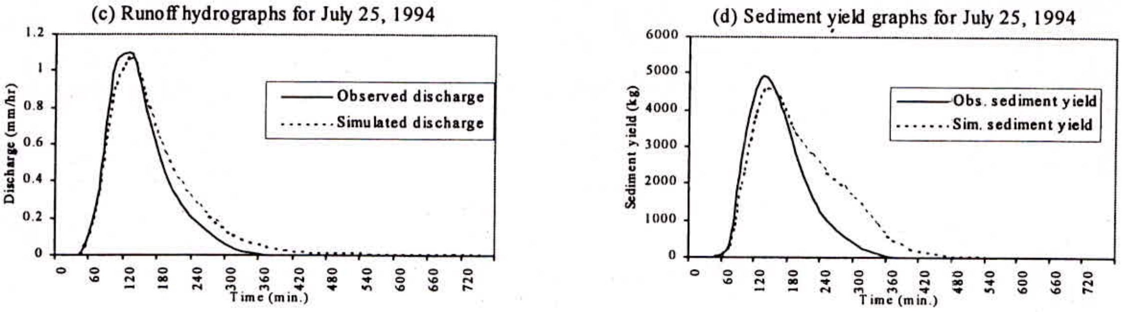
Spatial Distribution of Erosion and Deposition

Apart from predicting sediment yield rate at the watershed outlet, the model also predicted soil erosion and deposition rate in each cell of the watershed. These rates for the four events of calibration and validation were converted to maps using GIS techniques (Fig. 10). It can be observed from these maps that mostly insignificant erosion/deposition (-100 to 100 kg/ha) takes place in the areas having slope up to 1%. The high erosion areas (-500 to -3000 kg/ha), though very small in extent, coincide with higher slope areas (>3%). The erosion maps are very useful for understanding the erosion pattern of the watershed and for preparation of watershed management and treatment plans and also for mid-term evaluation of those plans. The RS and GIS techniques also offer high potential for accounting spatial variability in watershed characteristics and for generating input data for distributed models.

Fig. 9: Runoff hydrographs and sediment yield graphs for validation events


(a) Runoff hydrographs for June 23, 1994

(b) Sediment yield graphs for June 23, 1994


(c) Runoff hydrographs for July 25, 1994

(d) Sediment yield graphs for July 25, 1994

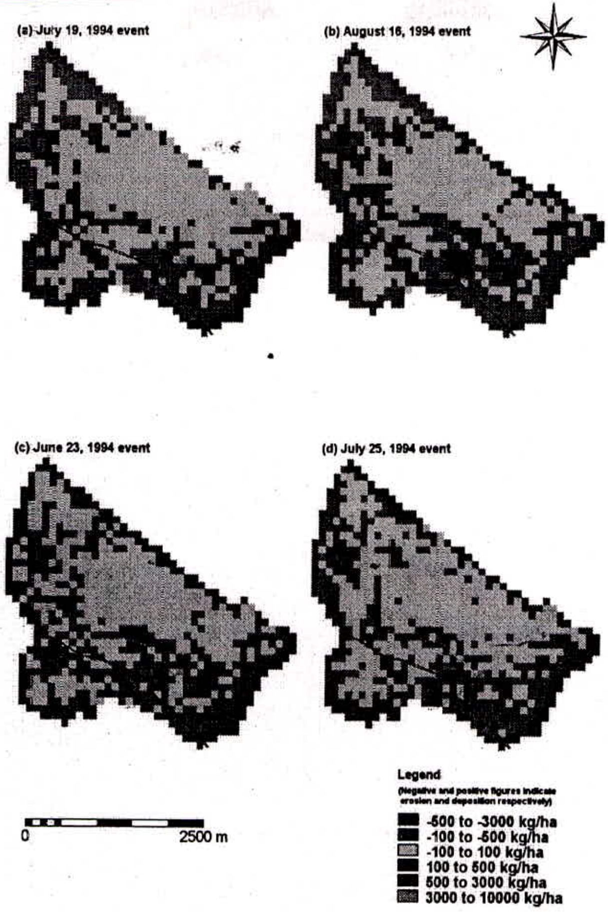


Fig. 10: Erosion and deposition maps

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